CO-COMBUSTION EVALUATION OF SPENT BLEACHING EARTH AND COAL: A STUDY CASE IN CEMENT INDUSTRY

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Abstract

As one of largest producers of greenhouse gas (GHG) emission, cement industries are committed to applying alternative ways to reduce the GHG emission level. Co-combustion of spent bleaching earth (SBE) and coal in cement industry is evaluated to reduce dependencies on fossil fuels. Such evaluation is conducted at one of cement plants in Indonesia owned by PT Indocement Tunggal Prakarsa Tbk. Palimanan Unit (PT ITP Palimanan Unit). Combustion in rotary kiln and calciner in two plant units (P9 and P10) were analyzed and compared. The comparison was conducted not only between plant units but also in different combustion operations, i.e., with and without SBE utilization as co-combustion agent. Several parameters consisting of temperature and gas compositions, which include CO, PM, SO_2, NO_2, CO_2, and O_2, were analyzed.

The study results show insignificant differences in the kiln temperature, while in the calciner, SBE utilization enhances temperature level by up to 40°C compared to the process without SBE. Based on gas composition measurement, slight discrepancies are observed between the two different combustion conditions, although different trends in average absolute value are obtained. NO_2 and PM concentrations are found to be slightly higher in the system without SBE, while an opposite trend is observed in SO_2 emission. The study also discovered that properties of raw coal and SBE influence the emission trend in the combustion system. This work highlights the potential of SBE co-combustion with coal to be applied in a continuous manner since it provides slightly higher energy conversion while maintaining nearly similar emission level. In addition, the utilization of SBE is found to not cause significant disturbance to the rotary kiln and calciner operations.

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1. Introduction

Greenhouse gas emissions and depletion of fossil fuels have driven the growing concerns to find new biomass sources as energy production (Usman et al., 2022). Industrial sectors are recorded as the main contributor of the emission of greenhouse gases such as CO_2. As much as 21.4 Gt CO_2 was released to atmosphere in 2017 and the cement industry contributed up to 5% of total global CO_2 emission (Benhelal et al., 2021). This contribution is predicted to increase every year especially in the developed countries including Indonesia, which has planned to allocate massive resources for infrastructure development in the future.

The cement production process requires extremely high energy and produces massive CO_2 emissions. Calciner and rotary kiln in the cement industry contributes the largest greenhouse gas (GHG) emission compared to other processes, i.e., approximately 90% of total GHG emission in cement industry. This includes 30-40% contribution from fossil fuel combustion and 50-60% contribution from $CaCO_3$ decomposition (Benhelal et al., 2012; Chatziaras et al., 2014). Therefore, several efforts are needed to reduce the negative impact of cement industry operation and the utilization of more renewable energy is considered to be one of the possible solutions. To support 2°C Scenario (2DS) by 2030, the cement industry needs to utilize more than 17.5% of total thermal energy production from alternative sources (International Energy Agency, 2018). This paper focuses on the effect of non-fossil fuels utilization in the performance of heat generation in calciner and rotary kiln units in one of Indonesia's cement plants, PT Indocement Tunggal Prakarsa Tbk. Palimanan Unit (PT ITP Palimanan Unit), located in Cirebon, West Java, Indonesia.

Most calciners and kilns in cement plants rely on coal as the main energy source. One measure initiated by PT ITP Palimanan Unit is using co-combustion technology by blending the coal with other fuels such as spent bleaching earth (SBE). Spent bleaching earth (SBE) is a residual adsorbent produced by the refinement of crude palm oil (CPO) in the cooking oil industry and classified as solid waste. Bleaching earth residue is a mixture of fresh bleaching earth and the hydrocarbon component of CPO. The hydrocarbon component is converted to coke or charcoal (Suhartini et al., 2011). As a result of its growth, SBE waste has become a major issue for the cooking oil industry (Seng et al., 2001). A bleaching process generally requires about 2.5–3% of SBE per weight of CPO. In Indonesia, it is estimated that approximately 4.8 million tons of SBE with high oil content are discharged as solid waste in 2019 (Tetrisyanda and Wibawa, 2022).

SBE is generally disposed by dumping onto landfills since its recovery method is still considered to be relatively expensive. A special dumping method for SBE is required due to its hazardous properties (Yuan et al., 2020) in that it may cause water and soil pollution as well as introducing fire risk. Therefore, several alternative measures have been carried out to further utilize SBE, although not in a large scale, which include oil recovery, fertilizer, animal feed, brick and tiles, briquette, and direct co-combustion with coal (Dijkstra, 2020). The direct co-combustion with coal proves to be very potential to be used in industrial calciners and kilns at cement plants due to the high level of calorific value and ashes in SBE. The high calorific value in SBE, due to its hydrocarbon content, can be beneficial to assure high heating rate generation inside a kiln (Yuan et al., 2020). The remaining unburnt trace materials from SBE might end up to be mixed with the clinker in the kiln. This might also offer an advantage in increasing cement quality considering that several prior reports have indicated SBE as a mixture of brick materials (Eliche-Quesada and Corpas-Iglesias, 2014; Nalobile et al., 2019; Wu et al., 2012).

Despite the potential advantages of SBE, only a limited number of studies on the direct utilization of SBE in calciners and kilns as co-combustion agent with coal can be found. Therefore, an industrial scale implementation is thoroughly carried in this study to evaluate combustion performance of co-combustion process of coal and SBE at PT ITP Palimanan Unit. Evaluation of several important parameters related to the combustion completion is presented, including temperature level, oxygen, and CO_2 concentrations. Additionally, different gaseous emission is also monitored, namely CO, PM, SO_2, NO_2 concentration in the flue gas. The information from this study can be used further as a basis of wider implementation of co-combustion of coal and SBE in other cement plants and other types of industries.

2. Methodology

2.1 Fuel properties

In this study, the coal is mixed with SBE and subsequently fed as fuel for the combustion process in the calciner. The SBE originated from several palm oil industries in Java Island, Indonesia, while most of the coal was supplied from several mining companies in Borneo Island, Indonesia. Both SBE and coal were stored in a well-ventilated roof storage to prevent moisturization. The basic properties of coal and SBE, namely ultimate, proximate, and heat content analysis, are summarized in Table 1.

2.2 Calciner and rotary kiln

The experimental observation of the study is focused on two units at PT ITP Palimanan Unit cement plant, i.e., rotary kiln and calciner. The schematic of calciner and rotary kiln working principle are depicted in Figure 2. Observations were conducted at two different plants, namely Plant 9 (P9) and Plant 10 (P10). The rotary kilns and calciners at both plants share similar dimensions and specifications.

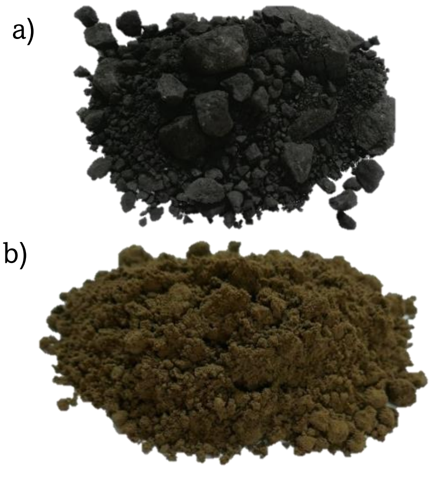

Figure 1 a) Raw coal; b) Raw spent bleaching earth

Table 1. Basic properties of coal and SBE

	Coal	SBE*
Ultimate analysis (wt.%)		
Carbon	57.31	15.5
Hydrogen	4.23	3.20
Oxygen	20.24	-
Nitrogen	0.86	0.48
Other trace elements	17.36	80.82
Proximate analysis (wt.%)		
Volatile	43.16	22.31
Ash	4.46	69.29
Fixed Carbon	39.60	0.32
Moisture	12.78	7.92
GHV (cal/g)	5589	2541

*proximate and ultimate data from (Yuan et al., 2020)

Several suspension preheaters were used before the limestone entered the calciner. The preheaters were used to increase the limestone temperature up to 800°C. The endothermic calcination reaction as depicted in R.1. occurred in the calciner to convert limestone to lime and CO_2.

$$CaCO_3 \rightarrow CaO + CO_2 \qquad \text{(R.1)}$$

The produced lime was directed to rotary kiln and proceeding reactions occurring in the kiln are summarized in R.2 to R.5. The rotary kiln is approximately 78 meters long and divided into several zones, namely calcining, safety, upper transition, burning, lower transition and cooling zones.

$$2CaO + SiO_2 \rightarrow 2CaO.SiO_2 \qquad \text{(R.2)}$$

$$3CaO + SiO_2 \rightarrow 3CaO.SiO_2 \qquad \text{(R.3)}$$

$$3CaO + Al_2O_3 \rightarrow 2CaO.Al_2O_3 \qquad \text{(R.4)}$$

$$4CaO + Al_2O_3 + Fe_2O_3 \rightarrow 4CaO.Al_2O_3.Fe_2O_3 \qquad \text{(R.5)}$$

The monitoring of combustion parameters was conducted using several techniques and equipment. Temperature was measured using high temperature pyrometer with maximum temperature of up to 1700°C. Temperature was measured both inside the kiln and calciner. Meanwhile, gas composition was measured at two different locations, i.e., at the inlet of the kiln (or the outlet of the calciner) using gas analyzer and at the stack area using continuous emission monitoring system (CEMS). At the stack sampling position, several parameters of exhaust gas were measured, namely CO, PM, SO_2, NO_2, CO_2, and O_2. Meanwhile at the inlet of kiln, the composition of O_2 in the gas phase are measured.

Temperature is recorded every 10 seconds while gas composition recorded every hour. In the current work, the presented and analyzed temperature measurement are conducted for about 2 hours during steady operation period. Meanwhile, 5 hours gas composition analysis is performed based on data for 5 hours of steady operation.

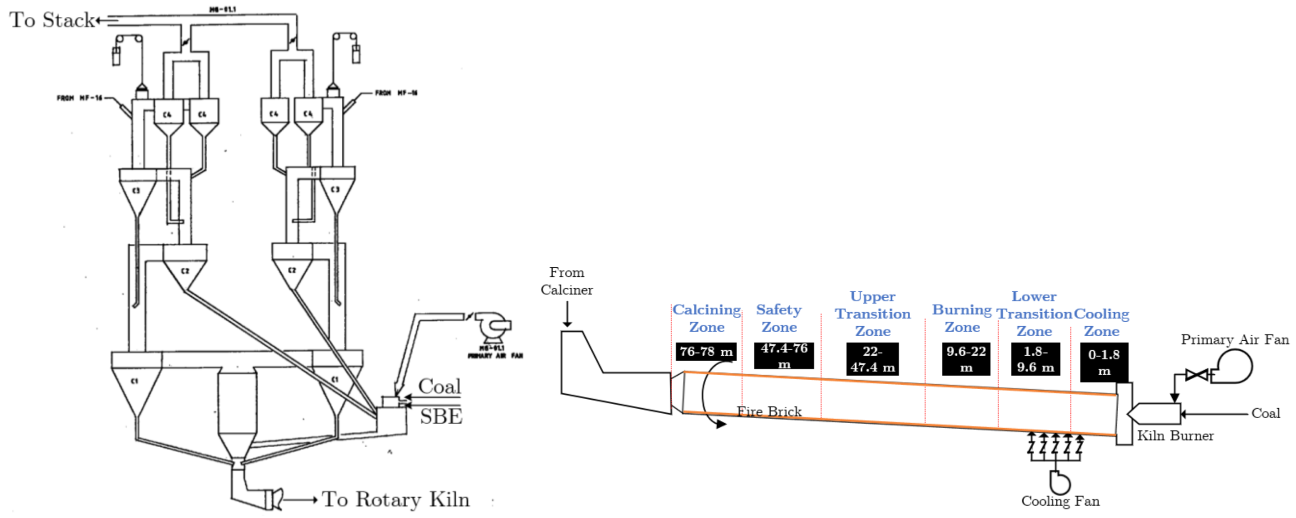

Figure 2 Schematic pictures of a) calciner and b) rotary kiln at PT ITP Palimanan Unit.

2.3. Feeding mechanism

Coal was supplied as fuel both in the rotary kiln and calciner. The raw coal from a well-ventilated roof storage was fed to the hopper using a conveyor belt and vibrating screen. The oversized coal was transported back to the storage, while the fine size coal was distributed further to two different rotor scales, namely rotor scale for kiln and for calciner burners. In the rotor scale, coal mass flow rate was regulated precisely. Coal and primary air were mixed in rotor scale and simultaneously directed to the burner. Air was supplied by a blower and penetrated via rotor scale holes. The air flowrate was regulated using a damper fan opening. The air flowrate adjustment was made based on the excess oxygen measured at the outlet of each equipment i.e., kiln and calciner. The design air flow rate was in the range of 3 to 3.5 Nm^3/mg clinker.

The feeding mechanism of SBE followed a similar mechanism to coal. The SBE from closed storage was fed to the hopper manually and was transported further to multiplex bin using a combination of belt and screw conveyors. Subsequently, the SBE was weighed in the weighing feeder before it was inserted into the calciner burner. The summarized scheme of feeding mechanism of coal and SBE is depicted in Figure 3.

Two different combustion conditions were utilized in the study, i.e., with SBE and without SBE. In the first condition, the flowrate of SBE fed to calciner burner was set to 11.5 tons/hour. On the other hand, the coal mass flowrate in the calciner and rotary kiln burner were set to 9.5 tons/hour and 15.7 tons/hour, respectively. In the second condition, total coal mass flowrate in the rotary kiln and burner were adjusted to 9.5 tons/hour and 19.5 tons/hour respectively.

3. Results & Discussion

Several different aspects were evaluated in the study to provide better knowledge of the combustion performance in the rotary kiln and calciner by including SBE as co-combustion agent with coal. Temperature and gas composition in the exhaust gas were among the evaluated parameters in the study.

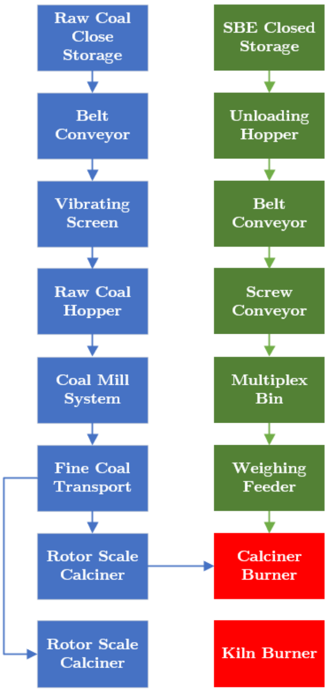

Figure 2 Feeding scheme of coal and SBE to kiln burner

3.1. Temperature profile results

The temperature profiles in the calciner and rotary kiln during combustion are summarized in Figure 4. High temperature pyrometer is utilized in the study to monitor the temperature level. A pyrometer is generally used to detect solid surface and captures its temperature including limestone and lime mixture, clinker, and wall temperature.

The graphs in Figure 4 are generated based on the average value from both P9 and P10 during 2 hours of steady operational conditions. It was discovered that there are no significant discrepancies between temperature profiles in both units at P9 and P10. The temperature measurement in Figure 4 highlights three different areas, namely the area inside the kiln (Kiln in), the area inside the calciner (Calc. in) and the kiln shell area (Kiln shell).

Based on the temperature profiles during 2 hours of steady operational conditions, the temperature level remained at relatively constant values, both in the rotary kiln and the calciner for different combustion conditions. Inside the kiln, the average temperature reached 1,000°C. The kiln shell temperature was stable at around 200°C. There were no significant discrepancies observed in the kiln temperature for both combustion with and without SBE.

Meanwhile, in the calciner, the two different combustion conditions resulted in different average temperature level. Inside the calciner, temperature reached a constant value of approximately 830°C in a condition without SBE and up to 870°C in the condition with SBE. This high temperature of the combustion with SBE can be attributed to the higher total fuel load compared to the condition without SBE. This implies the potency of SBE utilization in cement industry to provide higher temperature condition without generating any complexity to the process.

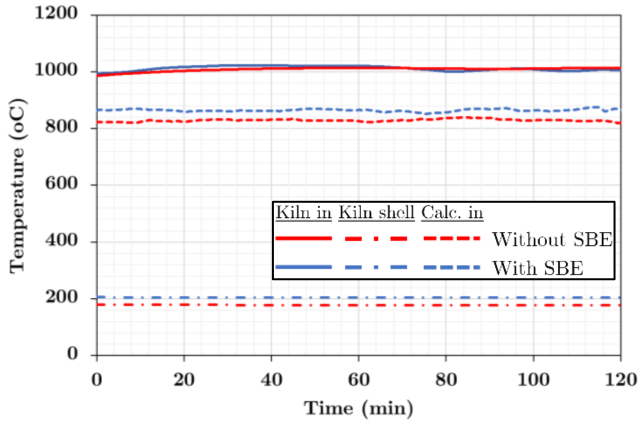

Figure 3 Feeding scheme of coal and SBE to kiln burner

Different temperature levels were observed inside the rotary kiln. The difference in temperature level corresponds to the different regions inside the kiln, i.e. calcining zone, safety zone, upper transition zone, burning zone, lower transition zone, and cooling zone. The lime mixture temperature increased from inlet to the inner region of kiln. Significant increase was recorded near the burner area or at burning zone. The maximum temperature identified was approximately 1,300°C in this zone. However, the temperature of solid mixture decreased before leaving the kiln at around 1,100°C.

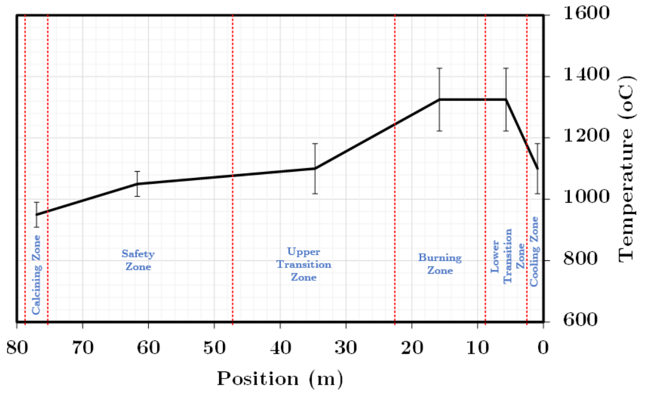

Figure 4 Temperature profile at different regions inside the kiln

3.2. Gas composition profiles

The composition of gas was monitored at two different locations, namely at the kiln inlet or at the outlet of calciner and at the stack area. At the kiln inlet, the gas composition measurements were conducted using a gas analyzer to record the O_2 composition. The oxygen composition measurement at this point was important as the basis of air flowrate adjustment at the kiln burner. The measurement results for O_2 at both P9 and P10 are presented in Figure 6. The gas analyzer sampled gas composition every hour and the gas composition presented in Figure 6 is the average of measurements over 5 hours of steady operation. The error bar represents the standard deviation from 5 data points recorded during 5 hours of operation.

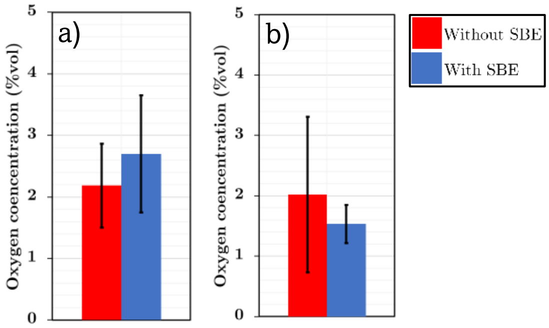

Figure 5 Measurement results of O_2 composition at the kiln inlet of: a) Plant 9 (P9) and b) Plant 10 (P10)

Based on Figure 6, the oxygen concentration in the process with SBE utilization in the combustion system does not indicate a significance difference at the kiln inlet. Approximately 1.5 to 2.7 vol% excess supply of oxygen was identified at the kiln inlet at both plant units. This highlights the potency of SBE utilization which could provide a relatively high degree of combustion stability or minimum level of disturbance to the global combustion process. Table 2 summarizes the average measured value from P9 and P10 units.

Besides measurement at the kiln inlet, a continuous emission monitoring system (CEMS) were utilized to monitor gas composition at the stack area. Several gaseous compounds, including CO, PM, SO_2, NO_2, CO_2, and O_2, were monitored to obtain information related to the emission level produced from the combustion system. The average measurement values over 5 hours of steady operation in P9 and P10 stack areas are presented in Figure 7. Taking the statistical error bars into account, no significant discrepancies were observed in the utilization of SBE in the calciner as shown in Figure 7. Table 2 summarizes the average measured values from P9 and P10 units.

On average, slightly higher SO_2 content at the stack was observed in the combustion process with SBE. This can be attributed to higher sulfur content in raw SBE compared to raw coal. On the other hand, the NO_2 emission at stack was discovered to be slightly higher in the combustion process without SBE. This can be attributed to nearly two times higher nitrogen content in raw coal compared to SBE as depicted in the ultimate analysis in Table 1. These trends were consistent in both P9 and P10 plant units. This result implies the notable influence of raw material properties to the emission level at the stack.

To assess combustion completion in the calciner, the O_2, CO_2, and CO concentrations are compared. Lower combustion efficiency was observed at P10 based on higher oxygen level and lower CO_2 at the outlet compared to P9. Higher CO level was also identified at P10 compared to P9. This might highlight operational issue at P10 which affected the combustion efficiency. Beside the operational issues between P10 and P9, insignificant discrepancies were observed between operation conditions with and without SBE at both plant units. This emphasizes that minimal disturbances occurred when SBE was introduced in the calciner burner system.

The final parameter captured by CEMS at the stack is particulate matters (PM) concentration in exhaust gas. Slightly higher PM concentration was identified in the combustion condition without SBE utilization. This trend was observed consistently at both plant units. The PM concentration in combustion without and with SBE amounted to be approximately 22.47 and 19.81 mg/m^3 respectively.

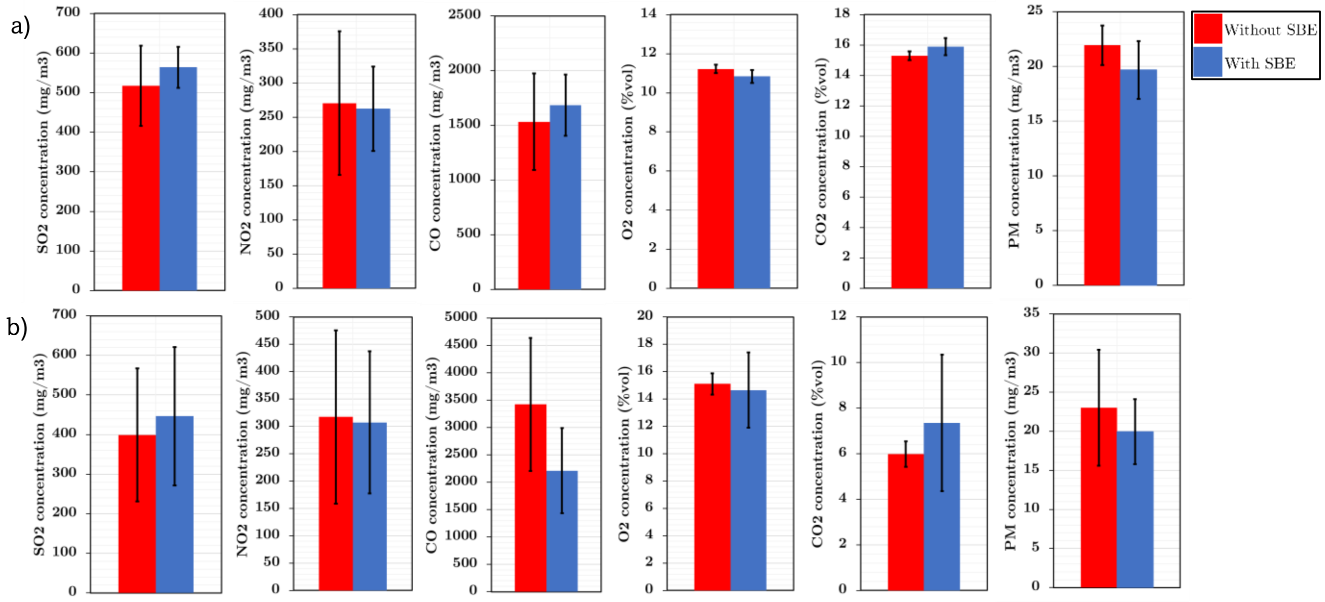

Figure 6 Measurement results of SO_2, NO_2, CO, O_2, CO_2, and PM composition in gas at the stack area, a) Plant 9 (P9) and b) Plant 10 (P10)

Table 2 Average gas composition measurement results at two plant units (P9 and P10)

Combustion parameters	**Fuel Type**			
	Coal + SBE		**Coal**	
Gas Analyzer (inlet rotary kiln)				
O_2 (% vol)	2.12	±0.63	2.10	±0.98
CEMS (stack)				
SO_2 (mg/m3)	505.15	±112.99	458.14	±134.88
NO_2 (mg/m3)	284.93	±95.75	293.96	±131.74
CO (mg/m3)	1947.91	±529.82	2477.96	±827.62
O_2 (%vol)	12.75	±1.54	13.17	±0.50
CO_2 (%vol)	11.62	±1.78	10.64	±0.42
PM (mg/m3)	19.81	±3.40	22.47	±4.60

PM in combustion system may consist of combination of three different components, namely condensed volatile compound, soot particle, and ash (Nugraha et al., 2021). Despite significantly higher content of ash in raw SBE compared to coal, it does not necessarily increase the PM concentration. This highlights a minor contribution of ash content in the raw material to the final PM emission. Ash content from SBE might end up with lime and/or limestone and carried in the process up to the final cement product. Therefore, the high content of condensed volatile compound and soot particle are suspected to present in the PM emission. This is also supported by higher content of volatile compound and carbon content in coal compared to SBE as analyzed from the ultimate and proximate analysis in Table 1.

4. Conclusion

Co-combustion of spent bleaching earth (SBE) and coal in cement industry is evaluated in the study. Combustion characteristics in the rotary kiln and calciner of PT ITP Palimanan Unit, Indonesia, were evaluated. Two different plant units (P9 and P10) were utilized in the study. The comparison was conducted not only between those two plant units but also in different combustion operation, i.e., with and without SBE utilization as co-combustion agent.

Different parameters consisting of temperature and gas compositions, i.e., CO, PM, SO2, NO2, CO2, and O2, were analyzed. Temperature observation was conducted using high temperature pyrometer which could measure a temperature of up to 1700°C. Meanwhile, gas composition measurements were conducted at two different locations, namely at the stack of calciner and in between calciner and kiln. Continuous monitoring emission system (CEMS) was used to monitor gas composition at the first location.

Meanwhile, a gas analyzer was used to monitor oxygen concentration in the second location.

Overall, the two plant units display almost similar combustion characteristics except for CO, CO2, and O2 concentration at the stack. Minor differences are observed in the combustion condition with and without SBE utilization. Insignificant differences are identified in the kiln temperature level, while in the calciner, the utilization of SBE enhances temperature level by 40°C compared to the condition without SBE. Based on gas composition measurement, slight discrepancies are observed between the two different combustion conditions, although different trends in average absolute value are obtained. NO2 and PM concentrations are indicated to be slightly higher in the system without SBE, while the opposite trend is identified in SO2 emission. It is concluded that the properties of raw coal and SBE influence the emission trend in the combustion system.

This study highlights the potential of SBE co-combustion with coal method to be applied in a continuous manner since it provides slightly higher energy conversion while maintaining almost identical emission level. Moreover, the utilization of SBE is also found to not cause significant disturbance to the rotary kiln and calciner operations.

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